

4-10-00

DOCKET NO.: 1819/100071
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BOX: PATENT APPLICATION

SIR:

Transmitted herewith for filing is the patent application (including Specification, Claims, Sequence Listing (if applicable) and Abstract, **25 pages**) of:Inventor(s): **Jeff B. Pelz**For : **METHOD AND SYSTEM FOR REDUCING NOISE IN A DIGITAL IMAGE AND APPARATUS THEREOF*****If a CONTINUING APPLICATION, please mark where appropriate and supply the requisite information below and in a preliminary amendment:*☐ continuation ☐ divisional ☐ Continuation-In-Part (CIP)
of prior application Serial No. _____Prior application information: Examiner :
Art Unit :

Enclosed are:

☒ **13 sheets** of formal drawings (**3 sets**).☐ **Signed** Combined Declaration and Power of Attorney (____ pages).☐ **Copy of signed** Combined Declaration and Power of Attorney (____ pages) from a prior application (1.63(d) (for continuation/divisional).☐ **Signed** statement deleting inventor(s) named in prior application (____ pages) (1.63(d)(2) and 1.33(b)).☐ **Incorporation By Reference:** The entire disclosure of the prior application, from which a **copy** of the oath or declaration is supplied herewith, is considered as being part of the disclosure of the enclosed application and is hereby incorporated by reference therein.☒ Assignment (**1 page**) of the invention to **Rochester Institute of Technology**.☒ Assignment Transmittal Letter.☐ Certified copy of a foreign priority document.☐ Associate power of attorney.☒ Verified statement to establish small entity status (**2 pages**) (newly signed or copy filed in prior application).JC553 U.S. PTO
04/07/00jc135 U.S. PTO
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09/545577 04/07/00

- ☐ Preliminary Amendment (_____ pages).
- ☒ Information Disclosure Statement, form PTO-1449 (**1 page**) and **11 references**.
- ☒ **UNSIGNED** Combined Declaration and Power of Attorney (**2 pages**).
- ☐ Statement in Accordance with 37 CFR § 1.821(f) and computer readable 3.5" Diskette.
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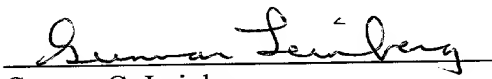
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R389788.1

EXPRESS MAIL CERTIFICATE

DOCKET NO. : 1819/100071

APPLICANT(S) : Jeff B. Pelz

TITLE : METHOD AND SYSTEM FOR REDUCING NOISE IN A
DIGITAL IMAGE AND APPARATUS THEREOF

Certificate is attached to the **Utility Patent Application Transmittal Letter**
(2 pages) in duplicate of the above-named application.


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Certificate is attached to the **Verification of Small Entity Status (2 pages)** of the above-named application.

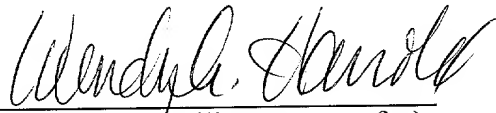
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Applicant or Patentee : **Jeff B. Pelz**
Serial or Patent No. : **To Be Assigned**
Filed or Issued : **Herewith**
For : **METHOD AND SYSTEM FOR REDUCING NOISE IN A
DIGITAL IMAGE AND APPARATUS THEREOF**

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) and 1.27(d)) - NONPROFIT ORGANIZATION**

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

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ADDRESS OF CONCERN : **5 Lomb Memorial Drive, Rochester, New York 14623-5603**
TYPE OF ORGANIZATION : **University**

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I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in 37 CFR 1.9(e) for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code with regard to the invention entitled **A METHOD AND SYSTEM FOR REDUCING NOISE IN A DIGITAL IMAGE AND APPARATUS THEREOF** by inventor(s) **Jeff B. Pelz** described in

- ☒ the specification filed herewith
☐ U.S. Provisional Patent Application Serial No.:
Filed:
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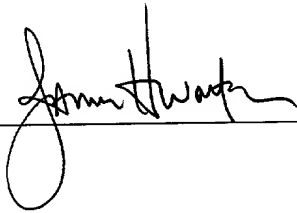
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NAME OF PERSON SIGNING : **James Watters, Ph.D.**
TITLE OF PERSON OTHER THAN OWNER : **Vice President, Finance & Administration**
ADDRESS OF PERSON SIGNING : **Rochester Institute of Technology**
5 Lomb Memorial Drive
Rochester, New York 14623-5603

SIGNATURE: _____



DATE: _____

April 7, 00

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APPLICANT(S) : **Jeff B. Pelz**

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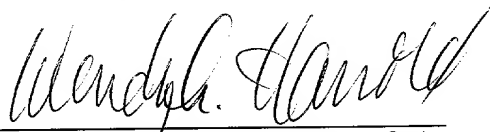
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Wendy L. Harrold

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TITLE: **METHOD AND SYSTEM FOR REDUCING NOISE IN
A DIGITAL IMAGE AND APPARATUS THEREOF**

INVENTOR: **JEFF B. PELZ**

DOCKET NO.: **1819/100071**

METHOD AND SYSTEM FOR REDUCING NOISE IN A DIGITAL IMAGE AND APPARATUS THEREOF

This application claims the benefit of U.S. Provisional Patent Application
Serial No. 60/128,931 filed on April 13, 1999 which is herein incorporated by
5 reference.

FIELD OF THE INVENTION

This invention relates generally to digital imaging and, more particularly,
to a method and system for reducing noise in a digital image.

10

BACKGROUND OF THE INVENTION

Electronic image sensors, such as charge-coupled devices (CCDs),
complementary metal oxide semiconductor (CMOS) sensors, and photodiode
arrays, are designed to capture image information by converting a spatially
15 varying electromagnetic exposure to a spatially varying analog and/or digital
signal. In an ideal sensor, the final signal is due only to the distribution of
electromagnetic (EM) energy collected at the image plane. Real sensors,
however, are also susceptible to thermal excitation. The result of the thermal
excitation is additive noise - false signal components due to non-image energy
20 within the sensor. All sensors, from the human retina to electronic sensor arrays,
suffer from this effect. Signals from electronic sensors are typically amplified,
exacerbating the effect.

Referring to Figure 1, a thirty second exposure captured on a CCD sensor
in a Kodak Professional DCS 315 digital camera is illustrated. The additive noise
25 in this digital image is clearly visible. It is also evident that the noise is not
equally distributed in spectral content.

While thermal excitation in the sensor array and subsequent processing are
responsible for the additive noise, the final effect is due to several interacting
influences. Because of image sensors' varying sensitivity to different wavelength
30 bands, system designs often include differential gain for each channel, leading to
more severe noise characteristics in the channels with higher gain. Many color

sensors have color filter arrays overlaying the sensor surface. These arrays often have different spatial sampling frequencies in the different color planes; the sampling density is typically highest in the green to optimize luminance-based resolution. One example of this is disclosed in U.S. Patent No. 3,971,065, which
5 is hereby incorporated by reference.

The additive noise varies with several variables, notably sensor temperature, exposure duration, and gain. As the sensor temperature is raised, thermal excitation within the sensor increases, leading to more pronounced noise levels. The duration of the exposure also plays an important role in the degree to
10 which noise degrades image quality.

Referring to Figures 2A-2F, the central region from a sequence of exposures ranging from 1 through 30 seconds is shown (the camera aperture was changed to maintain equal exposures throughout the sequence). The effect of thermal noise on images captured with electronic sensors places practical limits on
15 exposure duration without cooling. Current digital cameras restrict the exposure duration and/or caution users that long exposures may lead to a degradation of image quality. By way of example, the users guide for the Kodak DCS-315 digital camera warns that exposure durations greater than 0.25 seconds will lead to reduced image quality.

20 Noise in the final image is also a function of detector sensitivity and gain. Increasing the effective sensitivity of a system by, for example, increasing system gain, generally leads to increased noise. The resultant noise levels limit the practical sensitivity of modern digital cameras. Increasing the sensitivity has commercial value because the cameras can be used in lower illumination levels
25 and/or with shorter exposure times without electronic flash and the maximum distance at which a given flash is effective is increased. A technique for reducing apparent noise in digital imaging systems would enhance the value of digital camera systems and speed their acceptance for applications ranging from consumer photography to forensic imaging (for example).

Another variable affecting the noise characteristics in a digital imaging system is the sensor array itself. Specific pixels are subject to varying degrees of noise due to thermal and amplification variations. This characteristic is unlike detecting 'bad pixels' (or 'dark pixels' or other term) which vary in sensitivity.

5 One example of an apparatus for correcting faulty pixel signals by replacing the faulty pixel signals with normal pixel signals is disclosed in U.S. Patent No. 5,392,070, which is hereby incorporated by reference. Methods have also been described to correct for pixels' fixed offset such as in U.S. Patent No. 4,739,495, which is hereby incorporated by reference.

10 Pixels referred to in this invention are working sensor elements, and contribute fully to exposures made at relatively short exposures and/or processed at low amplification levels. They differ from the plurality of pixels by their susceptibility to noise.

The traditional approach to reducing the effects of additive noise in digital
15 images is the image processing technique known as median filtering. One example of median filtering is disclosed in U.S. Patent No. 4,783,753, which is hereby incorporated by reference. Such filtering techniques have also been applied to noise due to dust and scratches in images as disclosed, by way of example, in U.S. Patent No. 5,036,405, which is hereby incorporated by reference.

20 Other systems have been devised to reduce noise in systems by affecting different pixels differently, such as in U.S. Patent No. 4,858,013, which is hereby incorporated by reference, but none of these systems make use of information regarding pixels' fixed susceptibility to noise. The success of the system described here is due to the filtering method, as well as the identification and
25 mapping of image elements based on their noise susceptibility under varying exposure/processing conditions. The median filter operation replaces each pixel with the median value of the pixels that surround a particular pixel within a specified radius. The traditional median filtering technique also applies the same filter to every pixel in the red, green, and blue channels.

Unfortunately, the three-color sensors have different noise characteristics in each channel. This occurs for several reasons, chiefly because of the non-uniform spectral sensitivity and the effect of the subtractive filter array. Because the three channels have different characteristics, the optimum median filter for
5 each channel is not likely to be the same for each channel.

Referring to Figures 3A-3D, the effect of median filtering the fifteen second exposure shown in Figure 2E is shown. While it is evident that median filtering with progressively larger radii is effective in reducing additive noise, this approach also degrades image quality to a degree that makes the image
10 unacceptable.

SUMMARY OF THE INVENTION

A method in accordance with one embodiment of the present invention for reducing noise in a digital image includes providing a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data
15 signals and applying a filter to each of the sets of pixel data signals, where the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

A method in accordance with another embodiment of the present invention for reducing noise in a digital image includes a few steps. A digital image
20 comprising red, green, and blue channels is provided. Next, the red, green, and blue channels are transformed to an achromatic channel and two chrominance channels, where the achromatic channel and the two chrominance channels each comprise a set of pixel data signals. Next, a filter is applied to each of the sets of pixel data signals, where the filter applied to at least one of the sets of pixel data
25 signals is different from the filter applied to another one of the sets of pixel data signals.

A method in accordance with another embodiment of the present invention for reducing noise in a digital image includes a few steps. A digital image comprising a plurality of channels with each of the channels comprising a set of
30 pixel data signals is provided. Next, the pixel data signals in each set of pixel data

signals with at least a first characteristic are identified. Next, a filter is applied to the identified pixel data signals in each of the sets of pixel data signals.

5 An imaging system in accordance with another embodiment of the present invention includes an image sensing device and a filter system. The image sensing device captures a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals. The filter system comprises at least two different filters. Each of the filters at least one of the sets of pixel data signals for one of the channels.

10 An imaging system in accordance with another embodiment of the present invention includes an image sensing device, a transformation system, and a filter system. The image sensing device captures a digital image comprising red, green, and blue channels. The transformation system transforms the red, green, and blue channels to an achromatic channel and two chrominance channels. The achromatic channel and the two chrominance channels each comprise a set of
15 pixel data signals. The filter system comprises at least two different filters. Each of the filters filtering at least one of the sets of pixel data signals for one of the achromatic or chrominance channels.

20 An imaging system in accordance with another embodiment of the present invention includes an image sensing device, a masking system, and a filter system. The image sensing device captures a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals. The masking system specifies the pixel data signals in each set of pixel data signals with at least a first characteristic. The filter system applying a filter to the identified pixel data signals in each of the sets of pixel data signals. In this
25 embodiment, the mask identifies the pixels susceptible to noise at a given exposure, a range of exposures, an amplification value, or a range of amplification values. When masked before channel-specific filtering is applied, noise is reduced without adverse effects on the unmasked pixels, typically comprising a majority of pixels in each channel.

The present invention provides a number of advantages including reducing noise in images captured with digital cameras. More specifically, the present invention significantly reduces noise through an adaptive filtering technique which adjusts or customizes the filter for each channel of the image. The present invention is able to further improve the quality of the image by applying a color-space transformation before the filtering operation. The transformations allow important optimizations in the filtering process. The present invention is able to further improve the quality of the image by making a list (or an equivalent pixel map) of the pixels most susceptible to noise at a given level of exposure duration and amplification and then limiting the noise reduction or filtering processing to identified pixels on the list. By reducing noise in the images with the present invention, longer exposure times and increased sensitivity with digital cameras are possible. As a result, digital cameras will gain greater acceptance because of the higher image quality in a wide range of applications.

15

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a digital image using a thirty second exposure captured on a CCD sensor in a Kodak Professional DCS 315 digital camera;

Figures 2A-2F are digital images of the central region of Figure 1 from a sequence of exposures of one second, two seconds, four seconds, eight seconds, fifteen seconds, and thirty seconds (the camera aperture was changed to maintain equal exposures throughout the sequence);

Figures 3A-3D are digital images of the fifteen second exposure shown in Figure 2E with median filtering with progressively larger radii, but the same radius for each channel;

25

Figures 4A-4D are digital images of the fifteen second exposure shown in Figure 2E with median filters with different radii applied to the red, green, and blue channels in accordance with the present invention;

Figures 5A-5D are digital images of the fifteen second exposure shown in Figure 2E with a series of filters with different radii applied in CIELAB color space ("*Lab*") in accordance with the present invention;

Figures 6A-6B are digital images median filtered in CIELAB color space
5 without a noise mask and with a noise mask in accordance with the present invention;

Figures 7A-7B are digital images of the fifteen second exposure shown in Figure 2E with *Lab* median noise filter without a noise mask and with a noise mask in accordance with the present invention;

10 Figure 8A is a digital image in a red channel without any filtering;

Figure 8B is a digital image in a red channel with a masking filter in accordance with the present invention;

Figure 9A is a digital image in a green channel without any filtering;

Figure 9B is a digital image in a green channel with a masking filter in
15 accordance with the present invention;

Figure 10A is a digital image in a blue channel without any filtering;

Figure 10B is a digital image in a blue channel with a masking filter in accordance with the present invention; and

Figures 11A-11C are imaging systems in accordance with the present
20 invention.

DETAILED DESCRIPTION

Imaging systems 10 for reducing noise in a digital image in accordance with the present invention are illustrated in Figures. 11A-11C. A method for
25 reducing noise in a digital image in accordance with another embodiment of the present invention includes providing a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals and

applying a filter to each of the sets of pixel data signals, where the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals. The imaging system 10 which reduces noise in a digital image includes an image sensing device 12 and an image processing system 14. The system and method for reducing noise in a digital image provide a number of advantages including reducing noise in images captured with digital cameras.

Referring to Figures 11A-11C, the imaging system 10 includes an image sensing device 12 which captures the image. A variety of different types of image sensing devices 12 can be used, such as charge coupled devices, complementary metal oxide semiconductor sensors, and photodiode arrays, by way of example only. Typically, the image sensing device 12 will have a plurality of picture elements which sample the incident power or energy. The sampled values can then be transduced to an analog and/or digital signal suitable for processing, storage, or transmission. Once the image is captured by the image sensing device 12, the pixel data signals are transferred out to a memory 16 for storage and/or to an image processing system 14 for further processing.

In this particular embodiment, the image processing system 14 includes a central processing unit (CPU) 18 coupled to the memory 16 via a bus 20 which is coupled to the image sensing device 12, although the image processing system 14 may comprise other components as is well known to those of ordinary skill in the art. The memory 16 may be programmed with computer readable code to be executed by the CPU 18 to carry out the methods described in greater detail below. As shown in Figure 11C, the imaging system 10 may also include a system memory 16 and an image memory 24.

In this particular embodiment, the imaging system 10 includes a mask 22. The mask 22 can be defined at time of manufacture, as part of an inspection/quality assurance system, closer to point-of-sale, or can be generated from image statistics gathered during consumer use. In the latter case, the system could self-generate a mask 22 by monitoring individual pixel values across images, locating pixels that could be filtered, and the conditions under which they

should be filtered. While this implementation could under some conditions produce results not as effective as pre-programmed masks, the implementation allows a lower cost system that could be implemented in consumer-grade cameras without adding significantly to the manufacturing and associated costs.

5 Regardless of the manner in which the mask 22 is generated, it can be stored in memory 16, such as in a RAM, ROM, EPROM, EEPROM, or flash memory, or it could be incorporated in a signal-processing system associated with image capture/transfer.

10 The invention can be implemented as part of hardware design, as system software, as part of software used to transfer images from camera (or image memory), as stand-alone or 'plug-in' software, or in drivers (*e.g.* TWAIN).

15 The mask or masks 22 can be stored in a number of ways; for example as lists, as binary image maps, or encoded in a manner to minimize storage requirements. In another possible method, the masks 22 could be stored in the memory 16 normally assigned to, or useful for, image memory. A standard color image in memory 16 comprises three color planes, typically eight bits/plane. One implementation of the invention would place grayscale masks 22 in each of the planes. The masks 22 could be assigned to three image channels. The channels could be RGB, luminance/ chrominance (*e.g.*, CIELAB), or other representation.

20 Each mask 22 would comprise of a grayscale image, with the digital value at each pixel encoded to indicate over what exposure/processing conditions the pixel should be filtered. For example, a pixel value of 255 in the first mask channel could indicate that the images luminance value at that pixel should be filtered at any exposure greater than 0.25 seconds, while a pixel value of 128 would indicate

25 that the pixel should only be filtered at exposures greater than 5 seconds, etc.

30 In this particular embodiment, the image processing system 14 is programmed with a filtering process which customizes the filter for the pixel data signals for each channel, *e.g.* red, green, and blue channels or achromatic (luminance) and two chromatic (chrominance) channels, for the image, although the imaging system 10 can use other types of filtering processes or device. Since

filtering processes and devices are well known to those of ordinary skill in the art, they will not be discussed in detail here. In this particular embodiment, the filters are red, green, and blue median filters, although other types of filters could be used. The median filter for the red channel replaces the pixel data signal in each
5 filtered pixel with the median value of the pixel data signals in the pixels within a first set distance or radius of the filtered pixel, such as a radius of two pixels. The median filter for the green channel replaces the pixel data signal in each filtered pixel with the median value of the pixel data signals in the pixels within a second set distance or radius of the filtered pixel, such as a radius of one pixel. The
10 median filter for the blue channel replaces the pixel data signal in each filtered pixel with the median value of the pixel data signals in the pixels within a set distance or radius the filtered pixel, such as a radius of three pixels. Although one type of filter processing is carried out by the image processing system 14 in this particular embodiment, other processes or devices for filtering can also be used,
15 such as a filter wheel.

The imaging processing system 14 may also be programmed to convert the pixel data signals for red, green, and blue channels to an achromatic (luminance) and to chromatic (chrominance) channels. Since transformation techniques and systems are well know to those of ordinary skill in the art, they will not be
20 discussed in detail here. The above-described transformation allows for important optimizations in the filtering process resulting in higher image quality.

The image processing system 14 may also be programmed with a masking process which restricts application of the filters to pixels which have at least one characteristic or factor. Since mapping and masking processes in imaging are
25 well known to those of ordinary skill in the art, they will not be described in detail here. By way of example only, in this particular embodiment the characteristic or factor may be noise above a set threshold level. A map of pixels which are susceptible to noise and/or some other factor may be stored in memory 16 in the image processing system 14 and can be used to mask application of the filter to
30 certain identified pixels. Although the masking processing is carried out by the image processing system 14 in this particular embodiment, other processes or

devices for masking can also be used. The operation of the present invention will be described with reference to the following examples discussed below.

Referring to Figures 4A-4D, examples of applying median filters with the imaging system which have been customized for the red, green, and blue channels independently in accordance with one embodiment of the present invention are illustrated. In these examples, the images are labeled with the radii of the median filter for each channel applied by the imaging system 10, e.g., "R:2 G:1 B:3 " indicates that the red channel was filtered with a radius of two pixels, the green channel with a radius of one pixel, and the blue channel with a radius of three pixels. As these examples illustrate, the present invention dramatically reduces the apparent degradation due to noise in the image, while suffering less degradation of the image than the median filtering shown in Figures 3A-3D. In this particular embodiment, the filters are median filters which are implemented with the image processing system 14 in accordance with preprogrammed instructions in which each filtered pixel data signal in each pixel is replaced by the median value of the pixel data signals within a set radius from the filtered pixel data signal customized for each color channel, although other filtering processes and/or systems could be used.

By adjusting and applying the median filters independently in each image channel in the imaging system, each filter can be customized to that image plane, eliminating the need to over-filter some planes and/or leaving objectionable artifacts in other planes. The customized filtering used by the imaging system 10 can be adjusted as needed. For example, the filtering executed by the imaging system 10 can be predetermined and stored in memory 16 for use on every image, can be selected from a pre-defined lookup table which is stored in memory 16 based on some particular factor or factors, such as exposure duration and/or scene statistics, or can be customized each time based on an analysis of each captured image. The filtering operation can be applied by the imaging system 10 at the time of the exposure to the image sensing device 12 or at a later time.

While customizing and applying the filters to the red, green, and blue channels independently significantly increases the subjective image quality,

further improvements are possible by applying color-space transformations before the filtering operation by the imaging system 10. The method disclosed here and programmed into the memory 16 for execution by the CPU 18 converts the pixel data signals from red, green and blue channels to an achromatic (luminance) and two chromatic (chrominance) channels before filtering. The transformations allow important optimizations in the filtering process. The subjective percept of 'sharpness' is based largely on the high-frequency luminance information in an image, so minimizing filtering in that channel maximizes subjective image quality. More aggressive filtering by the imaging system 10 is then possible in the chrominance channels with less reduction in subjective image quality.

Referring to Figures 5A-5D, the fifteen second exposure from Figure 2E with a series of filters applied in CIELAB space (i.e. the achromatic (luminance) and the two chromatic (chrominance) channels) are illustrated. The image labels below these figures indicate the radii of the median filter which have been customized for each channel in CIELAB space and then applied to the luminance and chrominance channels. Again in this particular embodiment, the filters are median filters which are implemented with the image processing system 10 in accordance with preprogrammed instructions in which, each filtered pixel data signal in each pixel is replaced by the median value of the pixel data signals within a set radius from the filtered pixel data signal customized for each channel, although other filtering processes and/or systems could be used. The processed images which have been transformed to CIELAB space show a further reduction in image noise while maintaining the apparent image sharpness of the original.

While the described process of median filtering in a luminance/chrominance color space is able to reduce image noise with relatively few artifacts, it is possible to further reduce the artifacts by restricting the filtering process to pixels identified as likely to be influenced by additive noise. The method disclosed here and programmed into the memory 16 for execution by the CPU 18 in the image processing system 14 identifies which pixels are to be filtered in each of the channels and then masks or restricts the unidentified pixels from filtering. This extension allows image noise to be reduced while limiting the artifacts of the filtering process.

What the present invention has recognized is that while the bulk of the noise in digital systems is due to thermal noise in the image sensing device 12 or sensor during image capture (which is essentially a random process), it is evident that the image locations where the noise is most severe varies between image sensors but is relatively consistent across exposures. These variations are due to many factors, including variability in the microelectronic fabrication process of the chip used in the image sensing device 12 from silicon substrate manufacture through packaging. The noise is due to a stochastic process within each pixel, so the exact digital count at a pixel due to noise cannot be reliably predicted for any given exposure. However, individual pixels can be identified that are more susceptible to noise than other pixels. The noise characteristics of individual cameras or imaging systems 10 are relatively stable over time. By way of example only, the noise characteristics of one digital camera were monitored over a period of six months, and no significant variation was detected.

Accordingly, by making a list (or an equivalent pixel map) of the pixels most susceptible to one or more factors, such as noise above a threshold level, and storing it in memory 16 for use to restrict application of the filters to pixel data signals from certain pixels it is possible to limit noise reduction processing or filtering to identified pixels on the list. The result is that any artifacts of filtering remaining in the disclosed process are limited to the specific, limited regions of the image in which noise has been determined to be a problem. A variety of different method and system for mapping or identifying pixels to filter and those which are to be masked or restricted from filtering can be programmed into the memory 16 for execution by the CPU 18. By way of example, in a simple implementation the set of identified or 'noisy' pixels can include, for example, all pixel locations in the image that suffer from noise in a dark exposure of a given duration or it could include individual lists for each image channel (RGB or *Lab*, for example). The former would allow faster processing; the latter optimum image quality with minimal artifacts. Further reductions in artifacts are possible by for example identifying a different set of pixels for processing for each exposure duration (or for a range of exposures). Note that multiple lists could be

maintained individually or the ensemble could be stored in memory 16 as a multi-level image by encoding the different exposure durations as different pixel counts.

Such a technique would include a three-channel image (in RGB, *Lab*, or other color space), in which the digital count within each image represented an image filtration map for any exposure duration. By way of example only, the values in the L^* channel would encode the image sensing device's 12 or sensor's noise characteristics in the luminance channel. Image locations with value [0] would represent image locations that should not be filtered by the imaging system 10 because they have been shown to be least susceptible to noise even at very long exposure durations. These image regions could not suffer from any artifacts because they would not be altered by the filter. Image locations with value [1] could indicate pixels that are likely to suffer from substantial thermal noise in exposure durations over 30 seconds (for example). At very long exposures, these pixels (in this channel) would be filtered by the imaging system 10 and at shorter exposures they would not be filtered by the imaging system 10, and therefore would be protected against potential artifacts. Larger values in the image encode regions that suffer progressively more from thermal noise and would be included in shorter and shorter exposure durations. Note that this scheme would automatically correct for isolated defective pixels in the image that introduce noise in the image even at relatively short exposures.

The process could be easily extended to include pixels that produce values below optimum levels. Such pixels do not suffer from thermal noise; but rather they are less sensitive than surrounding pixels and result in dark (or black) pixels in the final image. One example of an apparatus for detecting inoperative pixels is disclosed in U.S. Patent No. 5,047,863, which is hereby incorporated by reference. Implementing a noise image including both noisy and dark pixels would allow manufacturers to use sensor chips for the image sensing device 12 that would otherwise fail quality control testing. Note that such an image could be compact because of the limited number of values that have to be stored. For example, an 8-bit image could encode all three channels by encoding two channel's noise maps in the bits 1-3 and 4-6, and the remaining channel's map in the remaining two bits. This scheme would allow 8, 8, and 4 different exposure durations for the three

channels. A 16-bit image could be split (6, 6, 5), to allow 64, 32, and 32 levels. A more complete mapping of a camera's noise characteristics could be stored in a traditional 24-bit image allowing 256 exposure durations in each of the three channels. Further savings could be achieved by standard image compression schemes; because most of the image include relatively large regions with [0]
5 values, compression would yield significant storage reduction.

Referring to Figure 6A, a resulting image from the imaging system 10 which used an *Lab* median noise filter without a noise mask is illustrated. Referring to Figure 6B, the same image resulting from the imaging system 10
10 which used an *Lab* median noise filter with a noise mask is illustrated. As these images illustrate there is a noticeable improvement in the resulting image when a masking process is implemented to restrict application of the filters to identified pixels.

It is evident that the noise reduction in a masked image is at least equal to
15 that processed without the mask, while the artifacts of filtering are reduced to nearly undetectable levels. Figure 7A shows the fifteen second image shown in Figure 2E after the whole image has been filtered in *Lab* color space, but without a masking process or system. While there are not severe artifacts, some reduction in apparent sharpness is visible in fine image details. By way of example only,
20 look at the detail in the eagle's wings and the star on the hat in Figure 7A. Figure 7B shows the image shown in Figure 2E after filtering in *Lab* color space and masking by the imaging system 10. In this particular example, filtering was accomplished in the imaging system 10 with a radius of two pixels in the L channel, four pixels in the *a* chrominance channel, and six pixels in the *b*
25 chrominance channel and a mask was used to restrict filtering to pixels identified as likely to generate noise in the image. As this example illustrates image quality is improved with the mask.

Referring to Figures 8A, 9A, and 10A, images captured by an imaging system without the present invention in the red, green, and blue channels,
30 respectively, are illustrated. Referring to Figures 8B, 9B, and 10B, images captured with an imaging system with a masked filtering process or system in

accordance with one embodiment of the present invention in the red, green, and blue channels, respectively, are illustrated. Enhanced image quality is evident in Figures 8B, 9B, and 10B, but the improvement in the blue channel shown in Figure 10B is the most dramatic in this particular embodiment. This particular
5 example demonstrates the utility of transforming the image to a luminance/chrominance color space in the imaging system 10 before filtering. The mask/filter technique can be applied directly to RGB image planes to limiting filtering artifacts, but noise reduction is less dramatic.

The demonstrated advantages of performing the filtering in *Lab* color
10 space in the imaging system 10 is due to the initial transformation from RGB to XYZ tristimulus values, and doesn't require the following non-linear transform from tristimulus space to *Lab*. As a result, substantial computational savings can be realized by programming the imaging system 10, in one particular embodiment, to implement the following: $RGB \rightarrow XYZ$ (or other color space):
15 median filter: $\rightarrow RGB$.

The imaging system 10 can also be programmed or implemented to work with the raw CCD/CMOS capture, before color interpolation has been completed. This may produce significant gains because noise in the raw image is spread during the interpolation step.

20 Accordingly, the present invention limits the apparent noise in images made with digital cameras and other imaging systems 10 of any type. The benefits of the present invention are most evident in situations requiring extended exposure times or enhanced sensitivity, such as scientific and forensic imaging or any case where it is desirable to capture images with limited illumination and/or
25 restricted apertures. Image quality which previously could only be found in film-based cameras, can now be found in digital cameras which use the present invention. The present invention can be implemented in and used in a variety of different systems, such as those spanning the range from low-cost 'point-and-shoot' cameras priced under \$400 to high-end six megapixel systems costing over
30 \$20,000. Dramatic reduction in noise with minimal artifacts has been demonstrated in all cases with the present invention.

Having thus described the basic concept of the invention, it will be rather apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications will occur and are intended to those skilled in the art, though not expressly stated herein. These alterations, improvements, and modifications are intended to be suggested hereby, and are within the spirit and scope of the invention. Accordingly, the invention is limited only by the following claims and equivalents thereto.

CLAIMS

What is claimed is:

1. A method for reducing noise in a digital image, the method comprising:
5 providing the digital image, the digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals; and
applying a filter to each of the sets of pixel data signals, wherein the filter applied to at least one of the sets of pixel data signals is different from
10 the filter applied to another one of the sets of pixel data signals.
2. The method as set forth in claim 1 wherein the step of applying a filter further comprises replacing each individual pixel data signal within the set of pixel data signals with a median pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data
15 signal.
3. The method as set forth in claim 2 wherein the set radius is different for the different filters.
4. The method as set forth in claim 2 further comprising adjusting the set radius of pixel data signals in the filter for each of the channels of the digital
20 image based on at least one factor.
5. The method as set forth in claim 3 wherein the factor comprises a duration of exposure for capturing the digital image.
6. The method as set forth in claim 1 wherein the plurality of channels comprises a red channel, a green channel, and a blue channel.
- 25 7. The method as set forth in claim 1 further comprising applying a color-space transformation to the sets of pixel data signals before the step of applying a filter.

8. The method as set forth in claim 1 further comprising:

identifying the pixel data signals in each set of pixel data signals with at least a first characteristic; and

restricting the application of the filters to the unidentified pixel data signals in each set of pixel data signals.

9. The method as set forth in claim 8 wherein the first characteristic is noise at or above a first threshold level.

10. A method for reducing noise in a digital image comprising:

providing the digital image comprising red, green, and blue channels;

transforming the red, green, and blue channels to an achromatic channel and two chrominance channels, wherein the achromatic channel and the two chrominance channels each comprise a set of pixel data signals; and

applying a filter to each of the sets of pixel data signals, wherein the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

11. The method as set forth in claim 10 wherein the step of applying a filter further comprises replacing each individual pixel data signal within the set of pixel data signals with a median pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data signal.

12. The method as set forth in claim 11 wherein the set radius is different for the different filters.

13. The method as set forth in claim 11 further comprising adjusting the set radius of pixel data signals in the filter for each of the channels of the digital image based on at least one factor.

14. The method as set forth in claim 13 wherein the factor comprises a duration of exposure for capturing the digital image.

15. The method as set forth in claim 10 further comprising:
identifying the pixel data signals in each set of pixel data signals
5 with at least a first characteristic; and
restricting the application of the filters to the unidentified pixel data signals in each set of pixel data signals.

16. The method as set forth in claim 15 wherein the first characteristic is noise at or above a first threshold level.

10 17. A method for reducing noise in a digital image, the method comprising:
providing the digital image, the digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals;
15 identifying the pixel data signals in each set of pixel data signals with at least a first characteristic; and
applying a filter to the identified pixel data signals in each of the sets of pixel data signals.

18. The method as set forth in claim 17 wherein the first characteristic
20 is noise at or above a first threshold level.

19. The method as set forth in claim 17 wherein the step of applying a filter further comprises replacing each individual pixel data signal within the set of pixel data signals with a median pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data
25 signal and wherein the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

20. The method as set forth in claim 19 wherein the set radius is different for the different filters.

21. The method as set forth in claim 19 further comprising adjusting the set radius of pixel data signals in the filter for each of the channels of the digital image based on at least one factor.

22. The method as set forth in claim 21 wherein the factor comprises a duration of exposure for capturing the digital image.

23. The method as set forth in claim 17 wherein the plurality of channels comprises a red channel, a green channel, and a blue channel.

24. The method as set forth in claim 17 further comprising applying a color-space transformation to the sets of pixel data signals before the step of applying a filter.

25. An imaging system comprising:
an image sensor apparatus for capturing a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals; and
a filter system comprising at least two different filters, each of the filters filtering at least one of the sets of pixel data signals for one of the channels, wherein the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

26. The system as set forth in claim 25 wherein the filters each replace each individual pixel data signal within the set of pixel data signals with a median pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data signal.

27. The system as set forth in claim 26 wherein the set radius is different for the different filters.

28. The system as set forth in claim 26 wherein the set radius of pixel data signals in the filter for each of the channels of the digital image is adjustable.

29. An imaging system comprising:
an image sensor apparatus which captures a digital image comprising red, green, and blue channels;
a transformation system coupled to the image sensor apparatus
5 which transforms the red, green, and blue channels to an achromatic channel and two chrominance channels, wherein the achromatic channel and the two chrominance channels each comprise a set of pixel data signals; and
a filter system comprising at least two different filters, each of the filters filtering at least one of the sets of pixel data signals for one of the
10 achromatic or chrominance channels, wherein the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.
30. The system as set forth in claim 29 wherein the filters each replace each individual pixel data signal within the set of pixel data signals with a median
15 pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data signal.
31. The system as set forth in claim 30 wherein the set radius is different for the different filters.
32. The system as set forth in claim 30 wherein the set radius of pixel
20 data signals in the filter for each of the channels of the digital image is adjustable.
33. An imaging system comprising:
an image sensor apparatus for capturing a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data
signals;
25 a masking system which identifies the pixel data signals in each set of pixel data signals with at least a first characteristic; and
a filter system applying a filter to the unidentified pixel data signals in each of the sets of pixel data signals.
34. The system as set forth in claim 33 wherein the first characteristic
30 is noise at or above a first threshold level.

35. The system as set forth in claim 33 wherein the filters each replace each individual pixel data signal within the set of pixel data signals with a median pixel data signal derived from a median value of adjacent pixel data signals within a set radius around the individual pixel data signal, wherein the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

36. The system as set forth in claim 35 wherein the set radius is different for the different filters.

37. The system as set forth in claim 35 wherein the set radius of pixel data signals in the filter for each of the channels of the digital image is adjustable.

38. The system as set forth in claim 33 further comprising a transformation system coupled to the image sensor apparatus which transforms the red, green, and blue channels to an achromatic channel and two chrominance channels, wherein the achromatic channel and the two chrominance channels each comprise a set of pixel data signals.

39. The system as set forth in claim 33 wherein the masking system comprises a memory for storing the identified pixels for the image sensor apparatus.

40. The method as set forth in claim 1 further comprising:
capturing the digital image with a sensor;
identifying pixels in a set of pixels for the sensor with a first characteristic;
storing a map of the identified pixels for the sensor; and
restricting the application of the filters to the pixel data signals in the unidentified pixels in the set of pixels for the sensor.

41. The method as set forth in claim 40 wherein the first characteristic is noise susceptibility above a first threshold.

5

identifying pixels in a set of pixels for the sensor with a first

storing a map of the identified pixels for the sensor; and

10

43. The method as set forth in claim 42 wherein the first characteristic is noise susceptibility above a first threshold.

ABSTRACT

A method for reducing noise in a digital image includes providing a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals and applying a filter to each of the sets of pixel data signals, where the filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals. An imaging system which reduce noise in a digital image includes an image sensor apparatus and a filter system. The image sensor apparatus captures a digital image comprising a plurality of channels with each of the channels comprising a set of pixel data signals. The filter system comprises at least two different filters with each of the filters filtering at least one of the sets of pixel data signals for one of the channels. The filter applied to at least one of the sets of pixel data signals is different from the filter applied to another one of the sets of pixel data signals.

EXPRESS MAIL CERTIFICATE

DOCKET NO. : **1819/100071**

APPLICANT(S) : **Jeff B. Pelz**

TITLE : **METHOD AND SYSTEM FOR REDUCING NOISE IN A
DIGITAL IMAGE AND APPARATUS THEREOF**

Certificate is attached to the **Three (3) Sets of Formal Drawings (13 pages)**
of the above-named application.

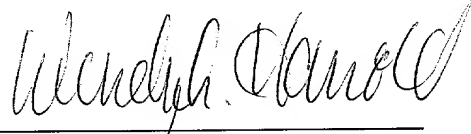
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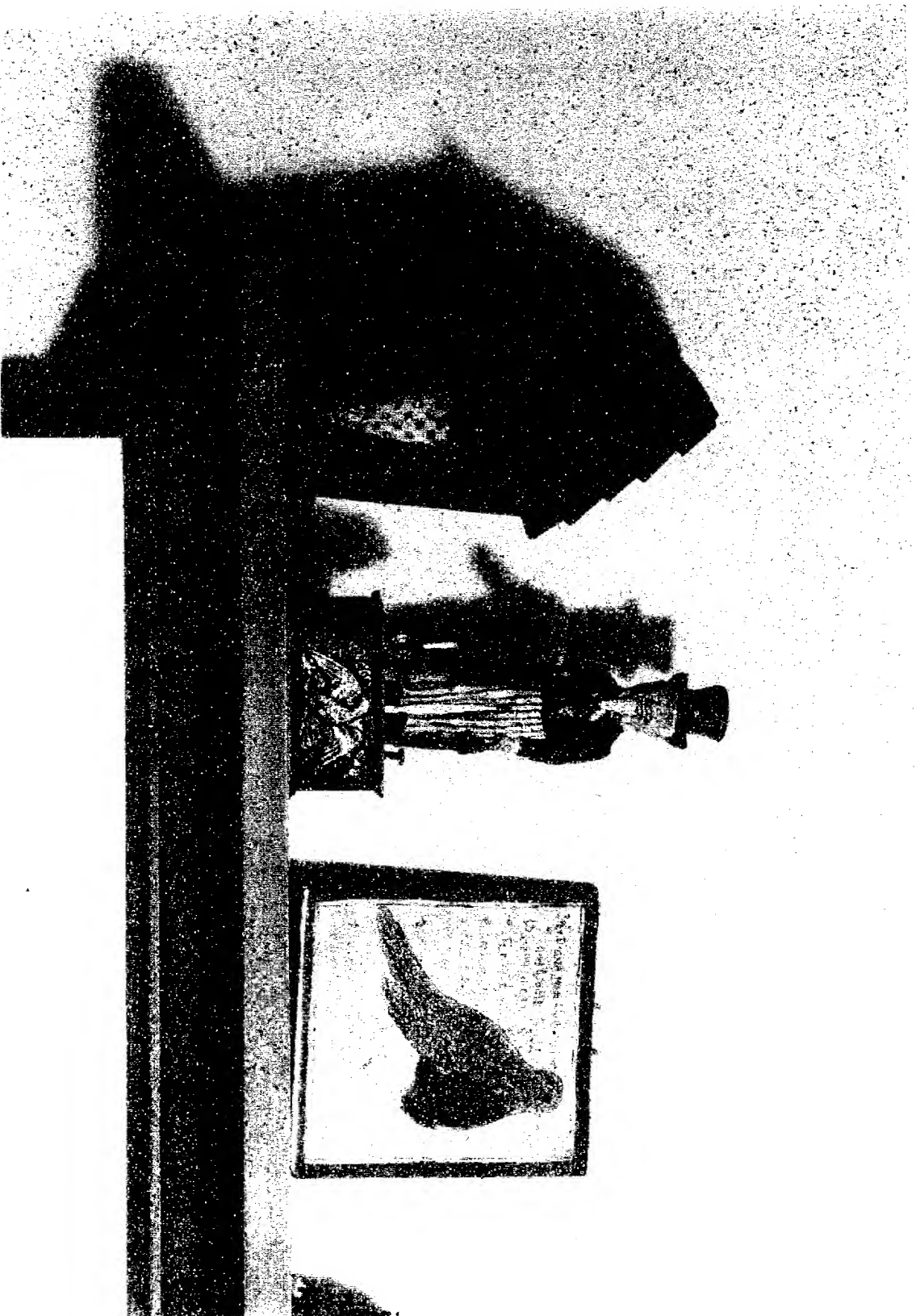


Figure 1
The Museum of the City of New York

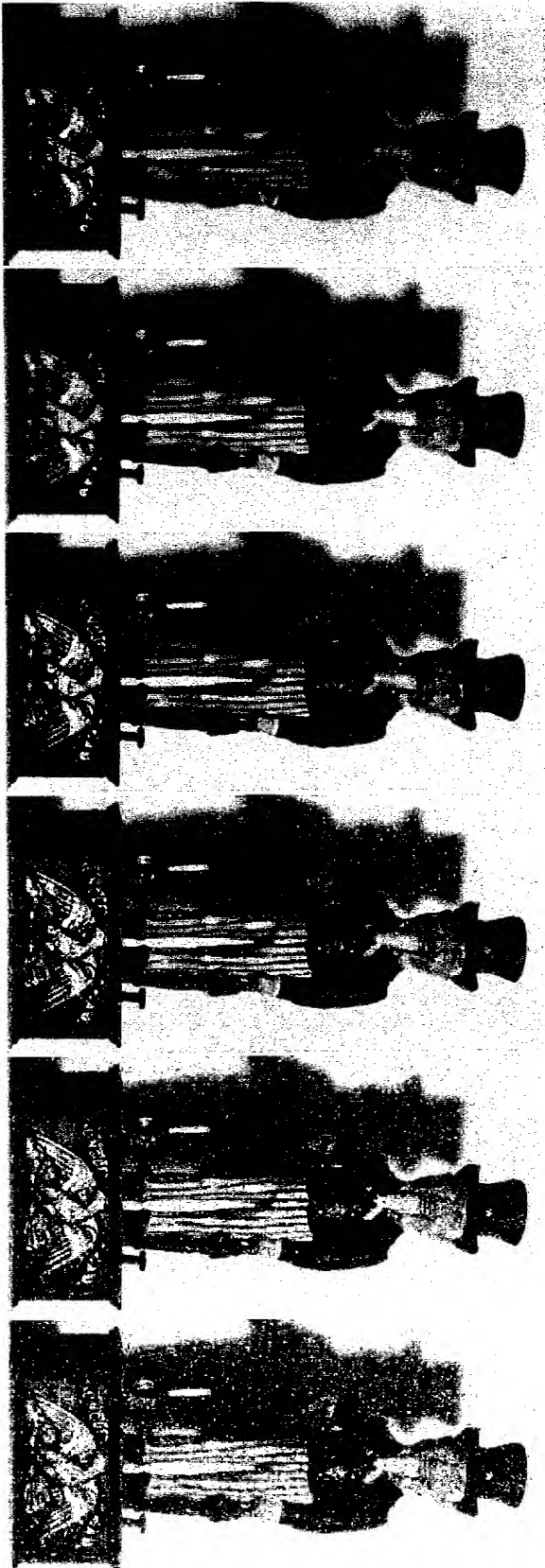


FIG. 2A

FIG. 2B

FIG. 2C

FIG. 2D

FIG. 2E

FIG. 2F



FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

00515577 000200

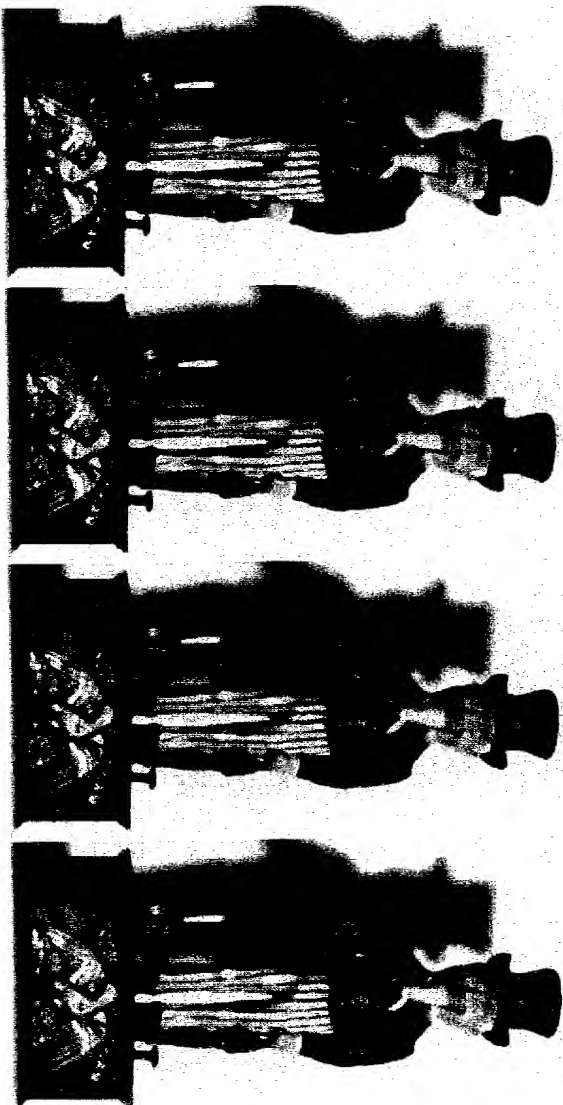


FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

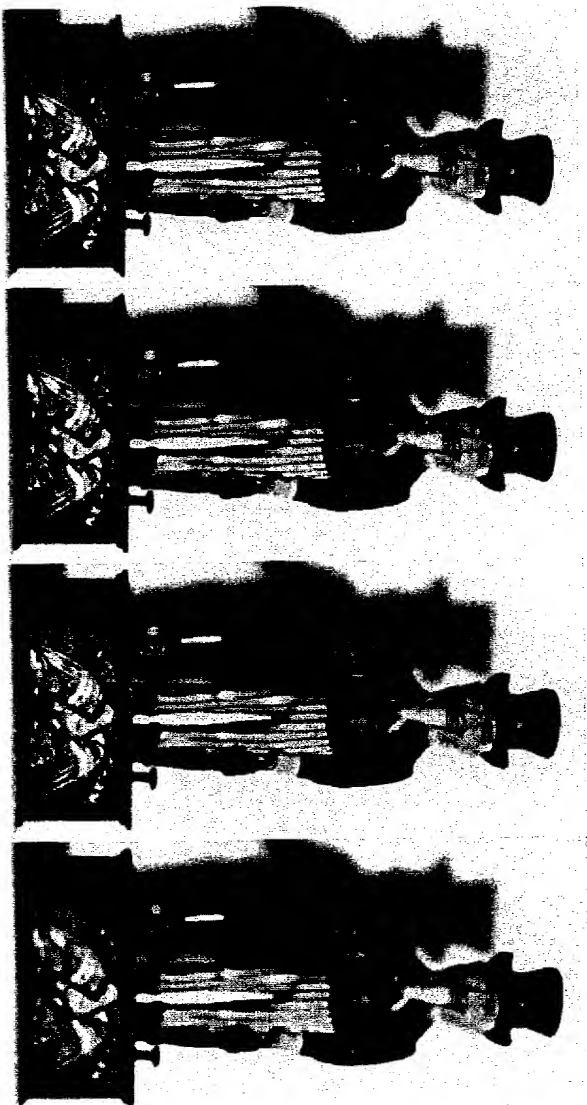


FIG. 5A

FIG. 5B

FIG. 5C

FIG. 5D

00545577 010700

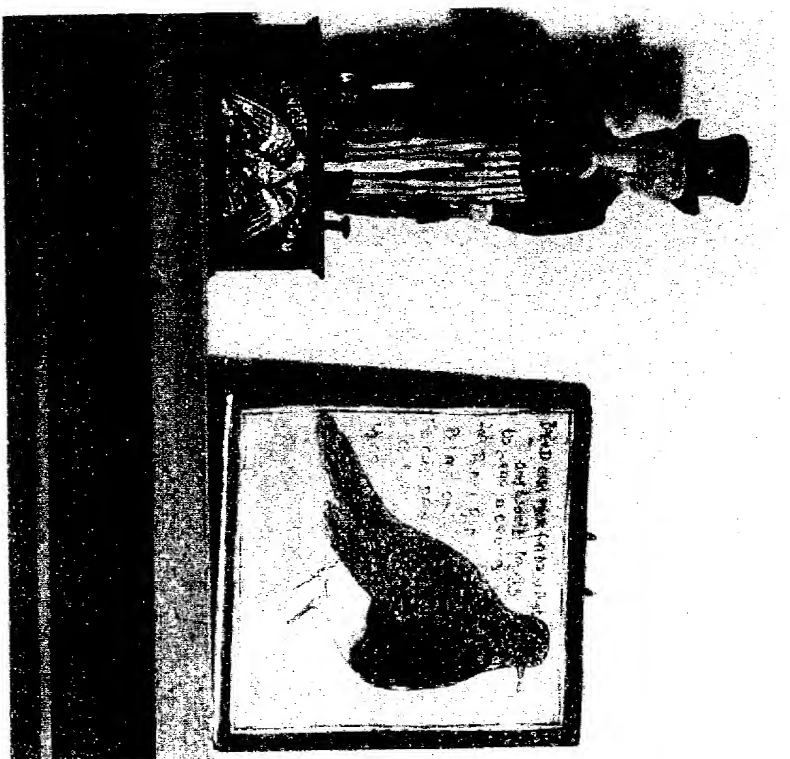
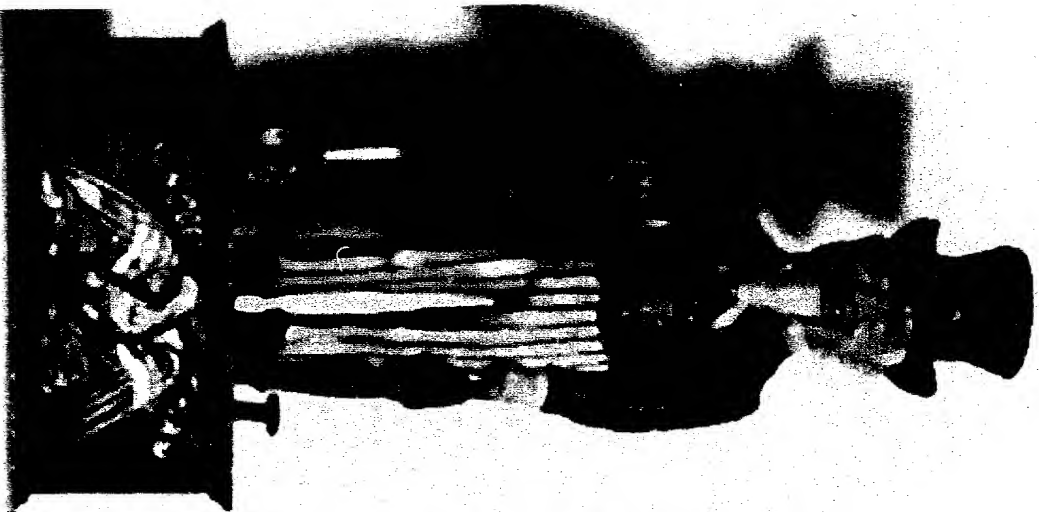


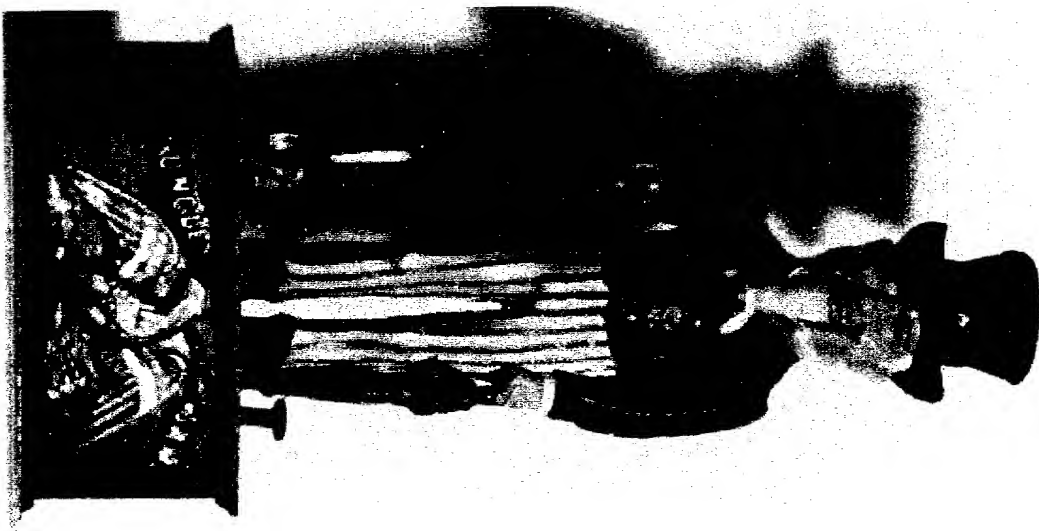
FIG. 6A



FIG. 6B



Lab median filter

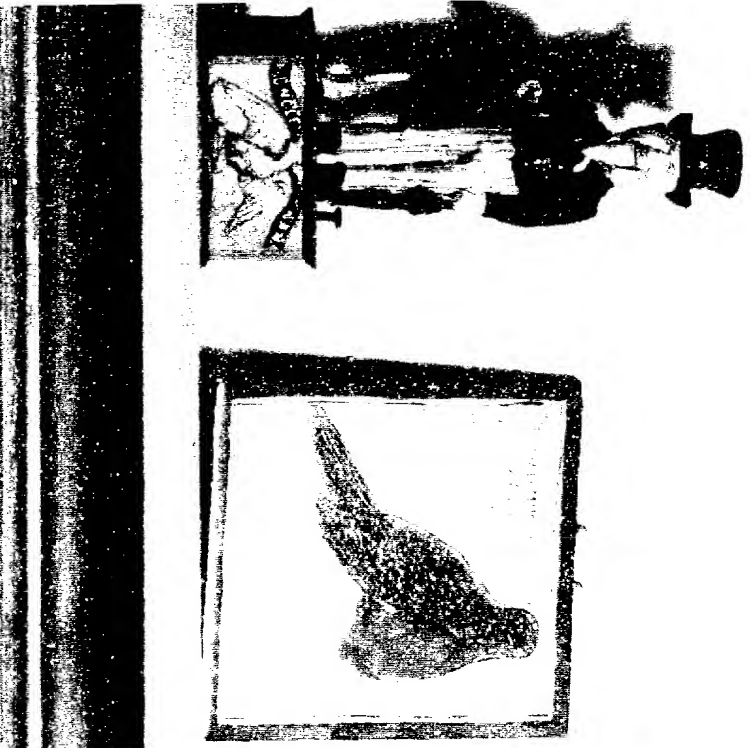


Lab masked filter

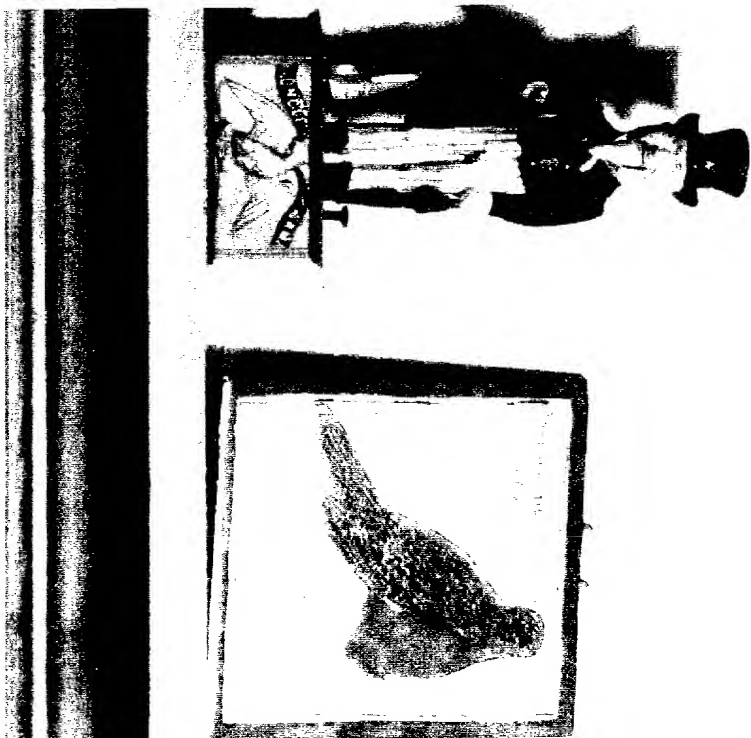
FIG. 7A

FIG. 7B

00515577 010700



15 sec capture (Red)



15 sec masked filter (Red)

FIG. 8A

FIG. 8B



15 sec capture (Blue)



15 sec masked filter (Blue)

FIG. 10A

FIG. 10B

00545577 000000

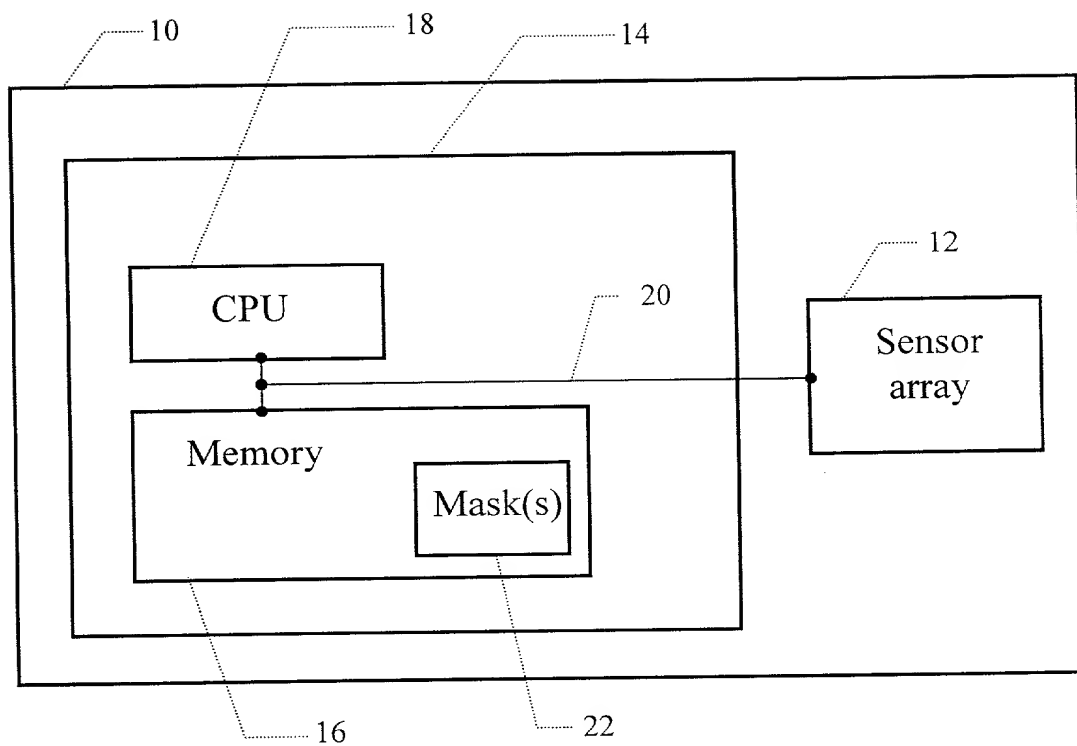


Figure 11a Mask in system memory

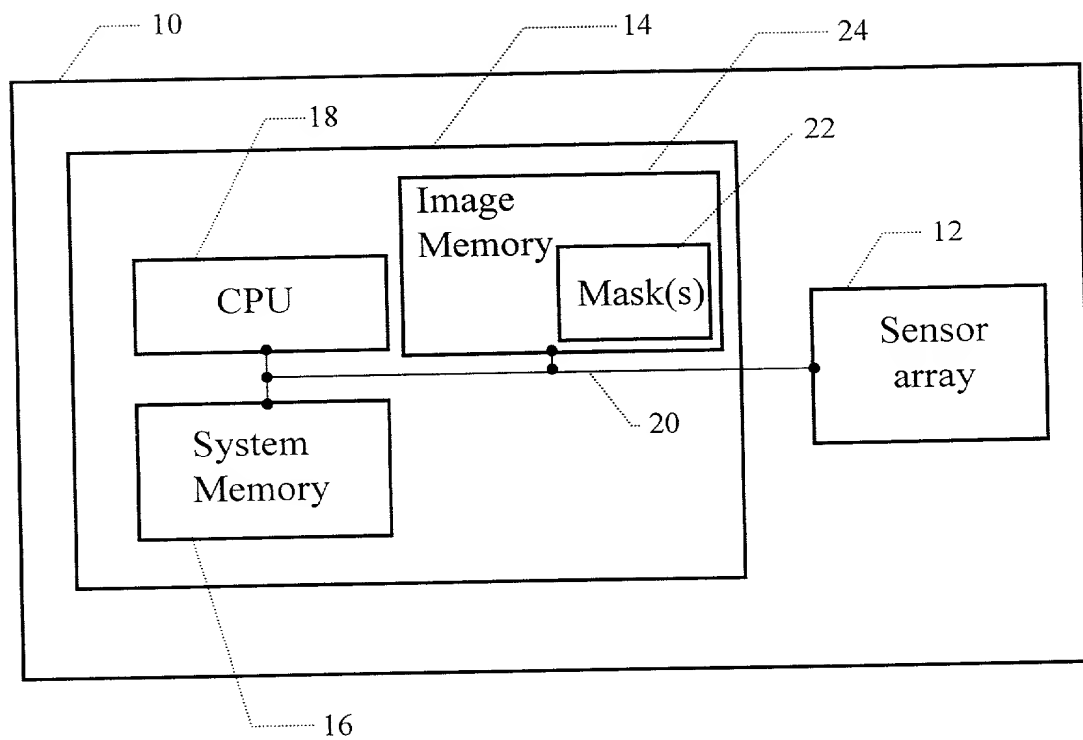


Figure 11c Mask in image memory

COMBINED DECLARATION FOR PATENT
APPLICATION AND POWER OF ATTORNEY
(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER
1819/100071

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD AND SYSTEM FOR REDUCING NOISE IN A DIGITAL IMAGE AND APPARATUS THEREOF

the specification of which (check only one item below):

☒ is attached hereto.

☐ was filed as U.S. Patent Application Serial No. _____ on _____ and was amended on _____ (if applicable).

☐ was filed as PCT International Application Number _____ on _____ and was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specifications, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (IF PCT, indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
U.S.A.	60/128,931	13 April 1999	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
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			<input type="checkbox"/> YES <input type="checkbox"/> NO

**COMBINED DECLARATION FOR PATENT
APPLICATION AND POWER OF ATTORNEY (Continued)
(Includes Reference to PCT International Applications)**

**ATTORNEY'S DOCKET NUMBER
1819/100071**

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT International filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (Check One)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.				
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)		

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. **Michael L. Goldman, Registration No. 30,727; Gunnar G. Leinberg, Registration No. 35,584; Dennis M. Connolly, Registration No. 40,964; Edwin V. Merkel, Registration No. 40,087; Georgia Caton, Registration No. 44,597; Grant E. Pollack, Registration No. 34,097**

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202	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/COUNTRY
203	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/COUNTRY

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201 UNSIGNED	SIGNATURE OF INVENTOR 202	SIGNATURE OF INVENTOR 203
DATE 4/7/2000	DATE	DATE